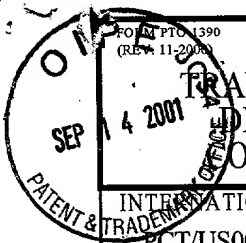


09-17-0410 Rec'd PCT/PTO 14 SEP 2001 CT



U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		NREL 99-17
U.S. APPLICATION NO. (If known, see 37 CFR 1.5)		09/936802
INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/US00/01434	21 JANUARY 2000	08 FEBRUARY 1999
TITLE OF INVENTION COOLING-TOWER FAN AIRFOILS		
APPLICANT(S) FOR DO/EO/US JAMES L. TANGLER AND DAN M. SOMERS		
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:		
<ul style="list-style-type: none">1. <input checked="" type="checkbox"/> This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.2. <input type="checkbox"/> This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.3. <input checked="" type="checkbox"/> This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.4. <input type="checkbox"/> The US has been elected by the expiration of 19 months from the priority date (Article 3 1).5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2))<ul style="list-style-type: none">a. <input checked="" type="checkbox"/> is attached hereto (required only if not communicated by the International Bureau).b. <input type="checkbox"/> has been communicated by the International Bureau.c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US).6. <input checked="" type="checkbox"/> An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).<ul style="list-style-type: none">a. <input type="checkbox"/> is attached hereto.b. <input checked="" type="checkbox"/> has been previously submitted under 35 U.S.C. 154(d)(4).7. <input checked="" type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))<ul style="list-style-type: none">a. <input type="checkbox"/> are attached hereto (required only if not communicated by the International Bureau).b. <input type="checkbox"/> have been communicated by the International Bureau.c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired.d. <input checked="" type="checkbox"/> have not been made and will not be made.8. <input type="checkbox"/> An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).9. <input type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).10. <input type="checkbox"/> An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).		
Items 11 to 20 below concern document(s) or information included:		
<ul style="list-style-type: none">11. <input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98.12. <input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.13. <input type="checkbox"/> A FIRST preliminary amendment.14. <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment.15. <input type="checkbox"/> A substitute specification.16. <input type="checkbox"/> A change of power of attorney and/or address letter.17. <input type="checkbox"/> A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.18. <input type="checkbox"/> A second copy of the published international application under 35 U.S.C. 154(d)(4).19. <input type="checkbox"/> A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).20. <input checked="" type="checkbox"/> Other items or information:		
Post Card Receipt		

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U.S. APPLICATION NO. 09/936802		INTERNATIONAL APPLICATION NO. <div style="text-align: center;">PCT/US00/01434</div>		ATTORNEY'S DOCKET NUMBER <div style="text-align: center;">NREL 99-17</div>	
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21. <input checked="" type="checkbox"/> The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO \$1000.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO \$860.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$710.00 International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) \$690.00 International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) \$100.00 <div style="text-align: center;">ENTER APPROPRIATE BASIC FEE AMOUNT</div>	CALCULATIONS PTO USE ONLY																										
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	<div style="border: 1px solid black; padding: 2px;">\$ 100.00</div> <div style="border: 1px solid black; padding: 2px;">\$ 130.00</div>																										
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 20%;">CLAIMS</th> <th style="width: 20%;">NUMBER FILED</th> <th style="width: 20%;">NUMBER EXTRA</th> <th style="width: 20%;">RATE</th> <th style="width: 20%;">\$</th> </tr> </thead> <tbody> <tr> <td>Total claims</td> <td>10 -20 =</td> <td>0</td> <td>x \$18.00 9</td> <td>\$ 0</td> </tr> <tr> <td>Independent claims</td> <td>5 -3 =</td> <td>2</td> <td>x \$80.00 40</td> <td>\$ 160.00</td> </tr> <tr> <td colspan="4">MULTIPLE DEPENDENT CLAIM(S) (if applicable)</td> <td>+ \$270.00</td> </tr> <tr> <td colspan="4" style="text-align: right;">TOTAL OF ABOVE CALCULATIONS</td> <td>= \$ 390.00</td> </tr> </tbody> </table>	CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	\$	Total claims	10 -20 =	0	x \$18.00 9	\$ 0	Independent claims	5 -3 =	2	x \$80.00 40	\$ 160.00	MULTIPLE DEPENDENT CLAIM(S) (if applicable)				+ \$270.00	TOTAL OF ABOVE CALCULATIONS				= \$ 390.00	<div style="border: 1px solid black; padding: 2px;">\$</div> <div style="border: 1px solid black; padding: 2px;">\$</div> <div style="border: 1px solid black; padding: 2px;">\$ 195.00</div>	
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TOTAL OF ABOVE CALCULATIONS				= \$ 390.00																							
<input checked="" type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.	<div style="border: 1px solid black; padding: 2px;">\$</div> <div style="border: 1px solid black; padding: 2px;">\$</div>																										
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Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property +			<div style="border: 1px solid black; padding: 2px;">\$</div>																								
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<div style="border: 1px solid black; padding: 2px; width: 100%;"> Amount to be refunded: </div>			<div style="border: 1px solid black; padding: 2px;">\$</div>																								
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- a. ☐ A check in the amount of \$ 14-0960 to cover the above fees is enclosed.
- b. ☒ Please charge my Deposit Account No. 14-1460 in the amount of \$ 195.00 to cover the above fees.
 A duplicate copy of this sheet is enclosed.
- c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any
 overpayment to Deposit Account No. 14-1460. A duplicate copy of this sheet is enclosed.
- d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card
 information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Paul J. White
 National Renewable Energy Laboratory
 1617 Cole Blvd.
 Golden, CO 80401

Paul J. White
 SIGNATURE

Paul J. White
 NAME

30.436
 REGISTRATION NUMBER

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COOLING-TOWER FAN AIRFOILS

By

James L. Tangler

Dan M. Somers

09/936802-032202

COOLING-TOWER FAN AIRFOILS

Technical Field.

5 This invention relates to the field of cooling-tower fans and specifically to a family of airfoils for use on the blades of such fans.

Background Art.

10 Large ducted fans are commonly used in the cooling towers of electric utilities to remove heat from the cooling water of heat exchangers. These fans are made up of four to twelve blades which range from 5 to 20 feet (1.5 to 6.1 meters) in length. A standard twelve foot (3.7 meter) blade employing the NACA 63₂ - 615 airfoil from root to tip has been the most commonly used blade in cooling tower applications. This airfoil is 15% cord thick, and it is designed for an operating lift coefficient of 0.6 with a low-drag-range that extends from a lift coefficient of 0.4 to 0.8. It was initially designed in the early 1940's for use in general
15 aviation and has been in use over the past 50 years. As a result, certain prior art design objectives have evolved over the course of these years.

The moist environment found in cooling tower applications causes soiling and leading edge corrosion of the fan blades. These conditions result in a roughness effect that reduces the overall aerodynamic performance and efficiency of the fan. Thus, one design objective
20 has been to improve the aerodynamic performance and reduce the sensitivity to roughness under these conditions, while operating at the maximum lift coefficient ($c_{l,max}$), in order to lower the power requirements on the system.

Optimization of the blade geometry and duct designs for large ducted fans would minimize the power that is required for a given thrust level or an associated pressure
25 increase. One way to increase the thrust-to-power ratio (T/P) is to reduce the drag coefficient of the blade's airfoils to cause a reduction in the power required to drive the blade. A maximum power reduction of 5% has been associated with zero profile drag for the blade. However, because zero drag cannot be accomplished, a realistic drag loss objective could result in a 2% power reduction.

30 The tip airfoil should be thin enough to provide low drag, but should also provide a maximum lift-to-drag ratio (l/d) at high values of lift coefficient to minimize blade solidity. In the hub region, blade-element performance predictions have indicated the presence of low

blade angles of attack. As a result, the root airfoil should produce a lift high coefficient at zero angle of attack. Designing new airfoils, having a minimal sensitivity to roughness, is therefore desirable should the blade operate in a stalled condition. Stalled conditions are usually caused either by an unsteady inflow or the low air density which is encountered when operating the fans at high temperatures.

One of the most desirable design objectives for good performance with a ducted fan is to satisfy the free-vortex flow condition. A fan satisfying the free vortex flow condition has the product of induced inplane swirl velocity and radius being constant along the span of the blade. This causes the radial pressure gradient to balance the centrifugal forces on the fluid and eliminates spanwise (radial) flow and losses due to turbulent mixing. The free-vortex condition dictates the product of local blade chord and lift coefficient. The product of these two parameters results in the necessary radial loading and the resulting fan thrust. The airfoil lift coefficient is derived for known inlet conditions of advance ratio, blade pitch, and twist angle. Therefore, either a value of lift coefficient or chord must be chosen and the other is calculated to provide an optimum combination along the span.

Near the tip region high values of lift coefficient increase the T/P ratio of the fan. Therefore, the operating lift coefficient is selected to coincide with the airfoil's best l/d ratio and the product of the lift coefficient and chord are selected in order to design the fan to a specific thrust, for a given diameter and number of blades.

Near the hub the blade requires high twist to achieve a positive angle of attack. Unlike the tip, it becomes undesirable to twist the blade root toward $c_{l, \max}$ and the solidity or blade chord must also increase to satisfy the free-vortex condition. Special care must be taken in the design so that the solidity does not become excessive resulting in adverse "cascade" losses.

In view of the foregoing considerations there is an apparent need to satisfy the foregoing design objectives by providing an airfoil useful in a large tapered/twisted fan blade application but which has an improved aerodynamic performance over the prior art. Improvements in the aerodynamic characteristics are needed to provide an advanced airfoil having a maximum lift coefficient ($c_{l, \max}$) that is designed to be largely insensitive to the effects of roughness and allows a lower solidity blade with lower cascade flow losses.

Disclosure of Invention.

Accordingly, it is an object of this invention to provide an airfoil family having an improved aerodynamic performance but which demonstrates a reduced sensitivity to roughness when operating at $c_{l, \max}$.

5 Another object of the invention is to provide an airfoil design that allows a lower solidity blade with lower cascade losses, lighter weight and greater cost efficiency.

It is yet another object of the invention to increase the performance gain of a fan by providing a new airfoil resulting in a 0.2 higher c_l for a given airfoil angle of attack which allows an 18% blade chord reduction for a 2000 LB (8900 newton) fan thrust.

10 These and other objects of the present invention will become apparent throughout the description of the invention that now follows. Unless specifically defined otherwise, all technical or scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing
15 of the present invention, the preferred methods and materials are now described.

Briefly, a family of airfoils is provided for a blade of a cooling-tower fan, wherein the blade has a root region and a tip region, the family of airfoils comprises an airfoil in the root region of the blade having a Reynolds number of 500,000, and an airfoil in the tip region of the blade having a Reynolds number of 1,000,000, and wherein each airfoil is characterized
20 by a maximum lift coefficient that is largely insensitive to roughness effects.

Brief Description of Drawings.

Figure 1 is a profile of the prior art airfoil, and the airfoil family according to the present invention.

Best Mode for Carrying Out the Invention.I. Airfoil Performance Prediction.

An analysis method of Borst was used to assess the performance of the prior art NACA 63₂ - 615 airfoil and to identify the aerodynamic improvements of the invention
30 herein. Borst, Henry V., "A New Blade Element Method for Calculating the Performance of High and Intermediate Solidity Axial Flow Fans," NASA-CR-3063, 1979. The Borst

analysis method uses a rigid-wake model in conjunction with a cascade theory to provide a blade-element analysis method able to use two-dimensional airfoil data.

$$\sigma c_l = 2 \cos(\beta_1 - \alpha_i) [\tan \beta_1 - \tan(\beta_1 - 2\alpha_i)] K(x)/K(x)_{\text{infinity}} \text{ (Eq. 1)}$$

5

In Eq. 1, σ is the local blade solidity; c_l is the section lift coefficient; β_1 is the inflow angle; α_i is the induced angle of attack that results from wake-induced inplane swirl; x is the non-dimensional radius; and $K(x)$ is Theodorsen's circulation function. $K(x)$ is a function of the number of blades, the wake advance ratio, and the radial position of the blade. $K(x)_{\text{infinity}}$ is Theodorsen's circulation function for a fan having an infinite number of blades. The values of $K(x)$ can be found using graphs from Borst, which were created using the rigid, helical-wake model of Gray and Wright. Gray, Robin B., and Terry Wright, "Determination of the Design Parameters for Optimum Heavily Loaded Ducted Fans," AIAA/AHS VTOL Research, Design, and Operations Meeting, February 17-19, 1969, AIAA Paper No. 69-222; Gray, Robin B., and Terry Wright, "A Vortex Wake Model for Optimum Heavily Loaded Ducted Fans," Journal of Aircraft, Vol. 7, No. 2, March-April 1970. The other main equation (Eq. 2) relates the flow angle and the induced angle to an equivalent two-dimensional angle of attack.

10

15

20

$$\alpha = \beta_1 - \phi - \alpha_i \text{ (Eq. 2)}$$

In Eq. 2, ϕ is the angle between the chord line and the plane of rotation. For a given blade, the equivalent two-dimensional angle of attack can be calculated knowing the induced angle of attack.

25

This method proceeds with the selection of an induced angle of attack that results for wake-induced, inplane swirl. Using this value, the values of σc_l are calculated using Eq. 1, directly, and Eq. 2 to find α for use with the two-dimensional airfoil data. The value of α_i is iterated upon until it results in an angle of attack and lift distribution that is compatible with the strength of the rigid-wake model. Equations 3 and 4 are then integrated to solve the blade-element equations for thrust and torque.

30

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$$T' = \frac{1}{2} \rho W^2 Bc(c_l \cos \phi - c_d \sin \phi) \text{ (Eq. 3)}$$

$$Q'/r = \frac{1}{2} \rho W^2 Bc(c_l \cos \phi + c_d \sin \phi) \text{ (Eq. 4)}$$

Certain simplifying assumptions have been associated with this method. The rigid, helical-wake assumption implies that the duct has a constant area in the axial direction and the fan is optimally loaded. The method assumes that there is no axial, induced velocity at the fan disc and that the airfoil's lift force is reacted by a pressure change. This technique also assumes that there are no duct- or hub-induced velocities.

It is further assumed that there is no flow about the blade tip or across blade stations. Therefore, secondary flow losses are not quantified. Application of the method to the invention herein also assumes that there is no acceleration or deceleration of the flow in the wake. In other words, the rotor advance ratio and the wake advance ratio were assumed to be equal.

II. Performance Characteristics and Geometry.

Figure 1 is a profile of the prior art NACA 63₂ - 615 airfoil (10). The upper surface of the airfoil (10) is shown at (12) and the lower surface at (13). The leading edge of the airfoil is at (14) and the trailing edge is at (15). The chord is shown at line (11). The NACA 63₂ - 615 airfoil has a thickness of 15%.

Figure 1 is also a profile of the tip airfoil (20), according to the present invention, relative to the prior art NACA 63₂ - 615 airfoil (10). The upper surface of the tip airfoil (20) is shown at (22) and the lower surface at (23). The leading edge of the tip airfoil is at (24) and the trailing edge is at (25). The chord is shown at line (21). The tip airfoil has a thickness of 10% chord.

The specific geometric tailoring of the tip airfoil (20) of Figure 1 is given in the form of the following table of coordinates. The x/c values are dimensionless locations along the blade chord line (21). They are given for both the upper (22) and lower (23) surfaces. The y/c values are the dimensionless heights from the chord line (21) to points either on the upper or lower surface.

TIP AIRFOIL 10%

UPPER SURFACE

x/c	y/c
1.00000	0.00000
0.99670	0.00088
0.98716	0.00373

General Information		Study Design		Study Population		Intervention		Outcome Measures		Results		Conclusions	
Author	Year	Design	Setting	N	Age (yr)	Intervention	Control	Primary Outcome	Secondary Outcome	Effect Size	Significance	Limitations	Strengths
Smith et al.	2015	RCT	USA	120	65	Group A	Group B	Survival at 1 year	Quality of life	0.15	0.05	Small sample size	High internal validity
Johnson et al.	2016	Cohort	UK	250	70	Group C	Group D	Survival at 2 years	Quality of life	0.20	0.01	Retrospective design	Large sample size
Williams et al.	2017	RCT	Canada	180	68	Group E	Group F	Survival at 1 year	Quality of life	0.18	0.02	Short follow-up	High external validity
Chen et al.	2018	Cohort	China	300	72	Group G	Group H	Survival at 3 years	Quality of life	0.22	0.001	Retrospective design	Large sample size
Miller et al.	2019	RCT	Australia	150	66	Group I	Group J	Survival at 1 year	Quality of life	0.16	0.03	Short follow-up	High external validity
Lee et al.	2020	Cohort	South Korea	280	71	Group K	Group L	Survival at 2 years	Quality of life	0.21	0.005	Retrospective design	Large sample size
Wong et al.	2021	RCT	India	160	69	Group M	Group N	Survival at 1 year	Quality of life	0.17	0.04	Short follow-up	High external validity
Patel et al.	2022	Cohort	USA	220	73	Group O	Group P	Survival at 2 years	Quality of life	0.23	0.002	Retrospective design	Large sample size
Kim et al.	2023	RCT	Japan	140	67	Group Q	Group R	Survival at 1 year	Quality of life	0.19	0.01	Short follow-up	High external validity
Nguyen et al.	2024	Cohort	Vietnam	260	74	Group S	Group T	Survival at 2 years	Quality of life	0.24	0.001	Retrospective design	Large sample size
Anderson et al.	2025	RCT	Sweden	130	68	Group U	Group V	Survival at 1 year	Quality of life	0.18	0.02	Short follow-up	High external validity
Thompson et al.	2026	Cohort	USA	240	75	Group W	Group X	Survival at 2 years	Quality of life	0.25	0.001	Retrospective design	Large sample size
White et al.	2027	RCT	Germany	170	69	Group Y	Group Z	Survival at 1 year	Quality of life	0.20	0.01	Short follow-up	High external validity
Black et al.	2028	Cohort	UK	210	76	Group AA	Group AB	Survival at 2 years	Quality of life	0.26	0.001	Retrospective design	Large sample size
Green et al.	2029	RCT	France	160	70	Group AC	Group AD	Survival at 1 year	Quality of life	0.21	0.02	Short follow-up	High external validity
Brown et al.	2030	Cohort	Canada	230	77	Group AE	Group AF	Survival at 2 years	Quality of life	0.27	0.001	Retrospective design	Large sample size
Miller et al.	2031	RCT	Italy	150	71	Group AG	Group AH	Survival at 1 year	Quality of life	0.22	0.03	Short follow-up	High external validity
Chen et al.	2032	Cohort	China	270	78	Group AI	Group AJ	Survival at 2 years	Quality of life	0.28	0.001	Retrospective design	Large sample size
Wong et al.	2033	RCT	India	180	72	Group AK	Group AL	Survival at 1 year	Quality of life	0.23	0.04	Short follow-up	High external validity
Patel et al.	2034	Cohort	USA	250	79	Group AM	Group AN	Survival at 2 years	Quality of life	0.29	0.001	Retrospective design	Large sample size
Kim et al.	2035	RCT	Japan	160	73	Group AO	Group AP	Survival at 1 year	Quality of life	0.24	0.05	Short follow-up	High external validity
Nguyen et al.	2036	Cohort	Vietnam	280	80	Group AQ	Group AR	Survival at 2 years	Quality of life	0.30	0.001	Retrospective design	Large sample size
Anderson et al.	2037	RCT	Sweden	170	74	Group AS	Group AT	Survival at 1 year	Quality of life	0.25	0.06	Short follow-up	High external validity
Thompson et al.	2038	Cohort	USA	290	81	Group AU	Group AV	Survival at 2 years	Quality of life	0.31	0.001	Retrospective design	Large sample size
White et al.	2039	RCT	Germany	190	75	Group AW	Group AX	Survival at 1 year	Quality of life	0.26	0.07	Short follow-up	High external validity
Black et al.	2040	Cohort	UK	300	82	Group AY	Group AZ	Survival at 2 years	Quality of life	0.32	0.001	Retrospective design	Large sample size
Green et al.	2041	RCT	France	200	76	Group BA	Group BB	Survival at 1 year	Quality of life	0.27	0.08	Short follow-up	High external validity
Brown et al.	2042	Cohort	Canada	310	83	Group BC	Group BD	Survival at 2 years	Quality of life	0.33	0.001	Retrospective design	Large sample size
Miller et al.	2043	RCT	Italy	210	77	Group BE	Group BF	Survival at 1 year	Quality of life	0.28	0.09	Short follow-up	High external validity

	0.97222	0.00863
	0.95269	0.01521
	0.92905	0.02278
	0.90137	0.03076
5	0.86962	0.03901
	0.83410	0.04761
	0.79539	0.05651
	0.75405	0.06552
	0.71067	0.07440
10	0.66582	0.08287
	0.62009	0.09058
	0.57397	0.09708
	0.52766	0.10192
	0.48128	0.10496
15	0.43504	0.10625
	0.38928	0.10586
	0.34435	0.10391
	0.30064	0.10051
	0.25854	0.09581
20	0.21849	0.08997
	0.18089	0.08313
	0.14614	0.07541
	0.11457	0.06695
	0.08648	0.05789
25	0.06211	0.04839
	0.04163	0.03863
	0.02516	0.02886
	0.01280	0.01937
	0.00455	0.01054
30	0.00047	0.00297
	0.00003	0.00066

LOWER SURFACE

	x/c	y/c
35	0.00004	-0.00070
	0.00037	-0.00179
	0.00120	-0.00266
	0.00254	-0.00346
	0.00771	-0.00536
40	0.02065	-0.00762
	0.03926	-0.00898
	0.06332	-0.00945
	0.09261	-0.00909
	0.12682	-0.00800
45	0.16562	-0.00627
	0.20860	-0.00402
	0.25530	-0.00138

	0.30519	0.00152
	0.35772	0.00455
	0.41227	0.00755
	0.46821	0.01041
5	0.52486	0.01296
	0.58152	0.01510
	0.63745	0.01667
	0.69190	0.01759
	0.74412	0.01779
10	0.79336	0.01725
	0.83888	0.01593
	0.87997	0.01390
	0.91590	0.01120
	0.94594	0.00809
15	0.96955	0.00501
	0.98647	0.00240
	0.99662	0.00063
	1.00000	0.00000

Figure 1 is also a profile of the root airfoil (30), according to the present invention, relative to the prior art NACA 63₂ - 615 airfoil (10). The upper surface of the root airfoil is shown at (32) and the lower surface at (33). The leading edge of the root airfoil is at (34) and the trailing edge is at (35). The root airfoil has a thickness of 14% chord

The specific geometric tailoring of the root airfoil (30) of Figure 1 is given in the form of the following table of coordinates. The x/c values are dimensionless locations along the blade chord line (31). They are given for both the upper (32) and lower (33) surfaces. The y/c values are the dimensionless heights from the chord line (31) to points either on the upper or lower surface.

ROOT AIRFOIL 14%

UPPER SURFACE

	x/c	y/c
	1.00000	0.00000
	0.99662	0.00114
	0.98703	0.00476
35	0.97233	0.01078
	0.95346	0.01852
	0.93085	0.02701
	0.90436	0.03546
	0.87375	0.04370
40	0.83919	0.05188
	0.80116	0.05998
	0.76012	0.06785
	0.71657	0.07535

[illegible]

	0.67101	0.08232
	0.62395	0.08859
	0.57590	0.09397
	0.52735	0.09831
5	0.47876	0.10147
	0.43059	0.10333
	0.38330	0.10381
	0.33728	0.10284
	0.29293	0.10039
10	0.25059	0.09648
	0.21061	0.09119
	0.17330	0.08462
	0.13897	0.07691
	0.10792	0.06822
15	0.08040	0.05875
	0.05665	0.04869
	0.03685	0.03828
	0.02116	0.02780
	0.00968	0.01758
20	0.00256	0.00808
	0.00019	0.00179

LOWER SURFACE

	x/c	y/c
25	0.00000	-0.00004
	0.00021	-0.00165
	0.00093	-0.00316
	0.00215	-0.00470
	0.00374	-0.00627
30	0.01354	-0.01266
	0.02846	-0.01889
	0.04821	-0.02465
	0.07252	-0.02979
	0.10113	-0.03414
35	0.13371	-0.03759
	0.16991	-0.04003
	0.20931	-0.04131
	0.25153	-0.04120
	0.29632	-0.03951
40	0.34354	-0.03619
	0.39294	-0.03140
	0.44418	-0.02524
	0.49710	-0.01784
	0.55160	-0.00978
45	0.60714	-0.00186
	0.66285	0.00525
	0.71775	0.01102

0.77079 0.01508
 0.82084 0.01719
 0.86679 0.01718
 0.90735 0.01506
 5 0.94113 0.01136
 0.96729 0.00713
 0.98565 0.00340
 0.99645 0.00088
 10 1.00000 0.00000

Industrial Applicability.

Table 1 summarizes the predicted performance characteristics for these new airfoils relative to the baseline prior art NACA 63₂ - 615 airfoil.

Airfoil	NACA 63 ₂ - 615 (tip airfoil/root airfoil)	S905 (tip airfoil)	S904 (root airfoil)
Station Reynolds Number	1,000,000/500,000	1,000,000	500,000
Thickness Ratio	15%/15%	10%	14%
$C_{l,max}$	1.25/1.20	1.50	1.50
C_l at 0 angle of attack	0.536/0.536	0.745	0.723
C_l at lower limit of low-drag range	0.20/0.20	0.65	0.05
C_l at upper limit of low-drag range	1.20/1.20	1.20	1.15
Drag coefficient at design c_l	0.009/0.010	0.007	0.008

In Table 1, the tip airfoil has less thickness than the baseline NACA 63₂ - 615 (10% versus 15%). This reduction in thickness results in a lower minimum drag (0.007 versus 0.009). At the design Reynolds number, the tip airfoil also has a higher $c_{l,max}$ (1.50 versus 1.256). The root airfoil is slightly thinner than the NACA 63₂ - 615 and has less drag in the root region (0.008 versus 0.010). It also has a larger c_l at zero angle of attack and a greater $c_{l,max}$. These improvements will lead to better performance in the root region.

Fan performance was calculated with the tip and the root airfoils using the baseline blade taper and twist geometry for the design thrust of 2000 LB (8900 newton). For the baseline blade the 2000 LB (8900 newton) thrust is achieved at a geometric pitch angle of 2°

versus 0° for the new airfoils. For these geometric blade-pitch angles, the new airfoils result in a performance gain of 1.5% for the eight-bladed 28-foot (8.534-meter) diameter fan. This gain does not take into account the gain that would be attributable to the airfoil's improved insensitivity to roughness where some measure of improvement is expected. It should be noted that the geometric pitch angle is with respect to the airfoil chord line which differs from a field pitch angle setting that is normally with respect to the lower surface of the airfoil. For the NACA 63₂ - 615 airfoil the field pitch setting is 4° greater than the geometric pitch angle.

Further gain is achieved by using the new airfoils with less blade chord than the baseline blade. The new airfoils are designed to operate at a 0.2 higher c_l than the baseline NACA 63₂ - 615 airfoil for a given blade pitch angle. One degree of blade pitch is equivalent to 0.1 c_l . This means that the new airfoils allow the blade chord to be reduced 18% by increasing the blade geometric pitch from 0° to 2° to satisfy the design thrust requirement of 2000 LB (8900 newton). The advantage of this tradeoff is that less blade chord results in less dimensional blade drag and the higher pitch angle still lies well within the airfoil's low-drag range. It is also predicted that this chord reduction will increase the performance gain to 1.8% at the 2000 LB (8900 newton) design thrust.

A similar reduction in chord to 82% for the baseline blade with the NACA 63₂ - 615 airfoil requires a blade pitch of 4° to achieve the 2000 LB (8900 newton) thrust. This results in a small performance gain relative to the baseline blade of 0.4%. The pitch increase from 2° to 4° is undesirable since it results in a noticeable reduction in the pitch margin to stall where fluctuating loads due to inflow variability become a problem.

An additional advantage using 18% less chord with the new airfoils is lower "cascade" losses due to reduced aerodynamic interference in the root region from lower solidity and corresponding lower blade weight and cost.

The foregoing description is considered as illustrative only of the principles of the invention. Furthermore, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and process shown as described above. Accordingly, all suitable modifications and equivalents may be resorted to falling within the scope of the invention as defined by the claims which follow.

Claims

1. A family of airfoils for a blade of a cooling-tower fan, wherein the blade has a root region and a tip region, the family of airfoils comprising an airfoil in the root region of the blade having a Reynolds number of 500,000, and an airfoil in the tip region of the blade having a Reynolds number of 1,000,000, and wherein each airfoil is characterized by a maximum lift coefficient that is largely insensitive to roughness effects.
2. The family of airfoils of claim 1 wherein the airfoil in the tip region has a maximum lift coefficient of 1.5, and the airfoil in the root region has a maximum lift coefficient of 1.5.
3. The family of airfoils of claim 2 wherein the blade is from 3 to 10 meters in length.
4. The family of airfoils of claim 2 wherein the tip-region airfoil has a thickness of about 10% chord, and the root region airfoil has a thickness of about 14% chord.
5. An airfoil for a blade of a cooling-tower fan wherein the blade has a root region airfoil having a cross-sectional shape characterized by a thickness of about 14% chord and a maximum lift coefficient of about 1.5 to be substantially insensitive to roughness, and a Reynolds number of 500,000.
6. The root region airfoil of claim 5 wherein the blade is 3 to 10 meters in length.
7. An airfoil for a blade of a cooling-tower fan wherein the blade has a root region airfoil comprises an upper surface and a lower surface and a blade chord line wherein x/c values are dimensionless locations along the blade chord line and the y/c values are dimensionless heights from the chord line to points on the upper or lower surface, wherein said values correspond substantially to the following table for said surfaces:

UPPER SURFACE

x/c	y/c
1.00000	0.00000
0.99662	0.00114
0.98703	0.00476
0.97233	0.01078
0.95346	0.01852
0.93085	0.02701
0.90436	0.03546
0.87375	0.04370
0.83919	0.05188
0.80116	0.05998
0.76012	0.06785
0.71657	0.07535

0.67101 0.08232
 0.62395 0.08859
 0.57590 0.09397
 0.52735 0.09831
 5 0.47876 0.10147
 0.43059 0.10333
 0.38330 0.10381
 0.33728 0.10284
 0.29293 0.10039
 10 0.25059 0.09648
 0.21061 0.09119
 0.17330 0.08462
 0.13897 0.07691
 0.10792 0.06822
 15 0.08040 0.05875
 0.05665 0.04869
 0.03685 0.03828
 0.02116 0.02780
 0.00968 0.01758
 20 0.00256 0.00808
 0.00019 0.00179

LOWER SURFACE

x/c y/c
 25 0.00000 -0.00004
 0.00021 -0.00165
 0.00093 -0.00316
 0.00215 -0.00470
 0.00374 -0.00627
 30 0.01354 -0.01266
 0.02846 -0.01889
 0.04821 -0.02465
 0.07252 -0.02979
 0.10113 -0.03414
 35 0.13371 -0.03759
 0.16991 -0.04003
 0.20931 -0.04131
 0.25153 -0.04120
 0.29632 -0.03951
 40 0.34354 -0.03619
 0.39294 -0.03140
 0.44418 -0.02524
 0.49710 -0.01784
 0.55160 -0.00978
 45 0.60714 -0.00186
 0.66285 0.00525
 0.71775 0.01102

0.77079	0.01508
0.82084	0.01719
0.86679	0.01718
0.90735	0.01506
0.94113	0.01136
0.96729	0.00713
0.98565	0.00340
0.99645	0.00088
1.00000	0.00000

10 8. An airfoil for a blade of a cooling-tower fan wherein the blade has a tip region airfoil having a cross-sectional shape characterized by a thickness of about 10% chord and a maximum lift coefficient of about 1.5 to be substantially insensitive to roughness, and an Reynolds number of 1,000,000.

9. The tip region airfoil of claim 5 wherein the blade is 3 to 10 meters in length.

15 10. An airfoil for a blade of a cooling-tower fan wherein the blade has a tip region airfoil comprises an upper surface and a lower surface and a blade chord line wherein x/c values are dimensionless locations along the blade chord line and the y/c values are dimensionless heights from the chord line to points on the upper or lower surface, wherein said values correspond substantially to the following table for said surfaces:

20 UPPER SURFACE

x/c	y/c
1.00000	0.00000
0.99670	0.00088
0.98716	0.00373
0.97222	0.00863
0.95269	0.01521
0.92905	0.02278
0.90137	0.03076
0.86962	0.03901
0.83410	0.04761
0.79539	0.05651
0.75405	0.06552
0.71067	0.07440
0.66582	0.08287
0.62009	0.09058
0.57397	0.09708
0.52766	0.10192
0.48128	0.10496
0.43504	0.10625
0.38928	0.10586
0.34435	0.10391
0.30064	0.10051

40

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	0.25854	0.09581
	0.21849	0.08997
	0.18089	0.08313
	0.14614	0.07541
5	0.11457	0.06695
	0.08648	0.05789
	0.06211	0.04839
	0.04163	0.03863
	0.02516	0.02886
10	0.01280	0.01937
	0.00455	0.01054
	0.00047	0.00297
	0.00003	0.00066
15	LOWER SURFACE	
	x/c	y/c
	0.00004	-0.00070
	0.00037	-0.00179
	0.00120	-0.00266
20	0.00254	-0.00346
	0.00771	-0.00536
	0.02065	-0.00762
	0.03926	-0.00898
	0.06332	-0.00945
25	0.09261	-0.00909
	0.12682	-0.00800
	0.16562	-0.00627
	0.20860	-0.00402
	0.25530	-0.00138
30	0.30519	0.00152
	0.35772	0.00455
	0.41227	0.00755
	0.46821	0.01041
	0.52486	0.01296
35	0.58152	0.01510
	0.63745	0.01667
	0.69190	0.01759
	0.74412	0.01779
	0.79336	0.01725
40	0.83888	0.01593
	0.87997	0.01390
	0.91590	0.01120
	0.94594	0.00809
	0.96955	0.00501
45	0.98647	0.00240
	0.99662	0.00063
	1.00000	0.00000

Abstract

5 A family of airfoils for a blade of a cooling-tower fan, is provided wherein the blade has a root region and a tip region, the family of airfoils comprises an airfoil (30) in the root region of the blade having a Reynolds number of 500,000, and an airfoil (20) in the tip region of the blade having a Reynolds number of 1,000,000, and wherein each airfoil is characterized by a maximum lift coefficient that is largely insensitive to roughness effects.

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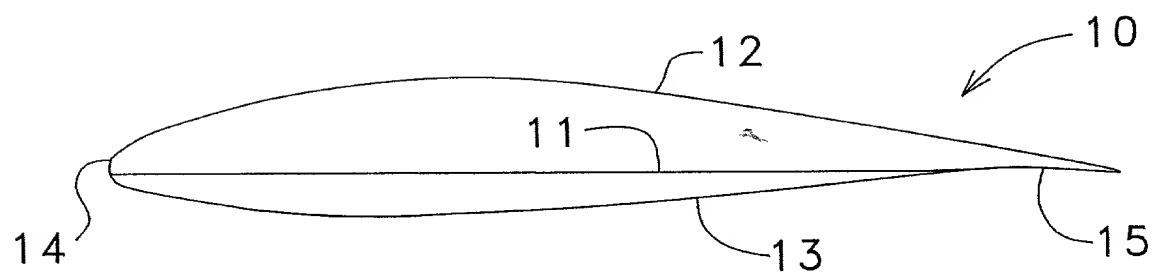


FIG. 1

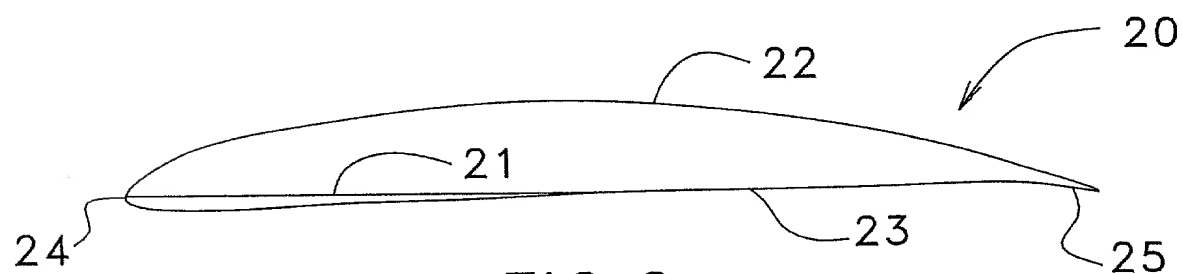


FIG. 2

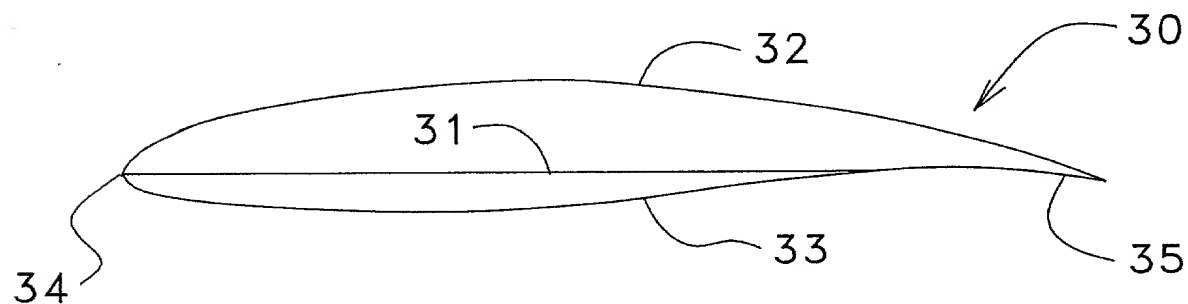
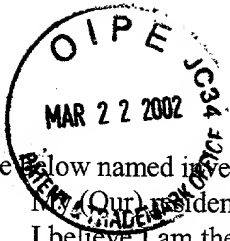


FIG. 3



COMBINED DECLARATION AND POWER OF ATTORNEY

As the below named inventor(s), I (we) hereby declare that:

I (Our) residence, post office address and citizenship(s) are as stated below next to my (our) name(s).

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled COOLING-TOWER FAN AIRFOILS

the specification of which (check one)

☐ attached hereto ☒ as filed on September 14, 2001 as Serial No. 09/936,802 and was amended _____

I (We) hereby state that I (we) have reviewed and understand the contents of the above-identified specification, including claims, as amended by any amendment referred to above.

I (We) acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I (We) hereby claim foreign priority benefits under Title 35, United States Code § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

PCT/US00/01742

21 January 2000

Number

Country

Filed (Day/Month/Year)

Priority
claimed

☒ ☐
Yes No

I (We) hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I (we) acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Serial No. 60/148,483

Filing Date 12 August 1999

Status Closed

POWER OF ATTORNEY: As the named inventor(s), I (we) hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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303/384-7575

We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Inventor's signature _____ Date _____
Residence _____ Citizenship _____
Post Office Address _____

Full name of joint inventor _____
Inventor's signature _____ Date _____
Residence _____ Citizenship _____
Post Office Address _____